An Introduction to Loki-Infect

An Agent-Based Model for Engineering Strategies to Mitigate the Impact of Influenza Epidemics

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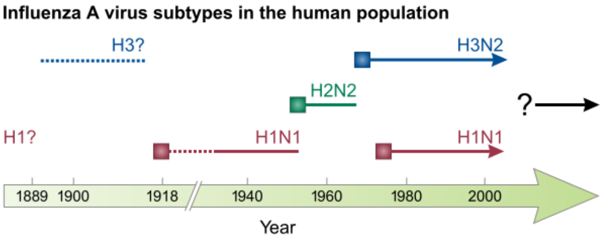
Outline

Seasonal Influenza

- Molinari et al. (2007) found that, in the United States alone, seasonal influenza is responsible for:
    - 610,660 (undiscounted) life years lost,
    - 3.1 million hospitalized days and 31.4 million outpatient visits,
    - annual direct medical costs averaging $10.4 billion, and
    - a total economic burden of $87.1 billion.

Pandemic Influenza

- Periodically, a novel strain of influenza is transmitted to humans from other animals (typically pigs and birds), causing a **pandemic**.



Major Pandemics of the 20th Century

1918 Spanish Flu (H1N1)

- Case fatality rate between 10% and 20%.
- Between 20 million and 100 million killed.

1957 Asian Flu (H2N2)

- Case fatality rate: 0.13%.
- 1.0 to 1.5 million deaths.

1968 Hong Kong Flu (H3N2)

- Case fatality rate: $< 0.1\%$.
- 0.75 to 1.0 million deaths.

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Recent scares

2003 Avian Flu (H5N1)

- 510 cases in humans, resulting in 303 deaths.
- Little evidence of human-to-human transmission.

2009 Swine Flu (H1N1)

- Total worldwide deaths: 14,286.
- Many similarities to 1918, including disproportionately high incidence of infection and fatality among young people.
- First global pandemic since 1968.

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- Neuraminidase inhibitors (antivirals)
  - Effective at treating and preventing infection by susceptible strains.
  - However, because of the high mutation rate of influenza, resistant strains are quick to emerge.
- Vaccine
  - Highly effective at preventing infection.
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- Personal protective equipment (facemasks, etc.)
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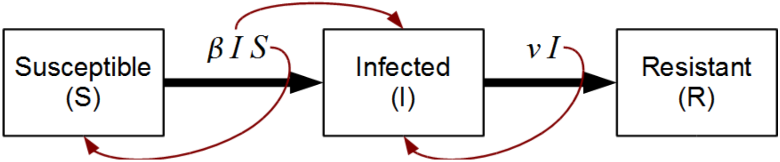
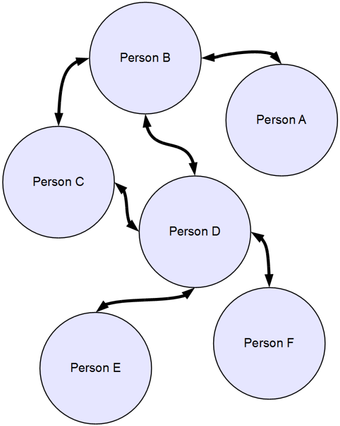
SIR Models



$$\frac{dS}{dt} = -\beta IS$$
$$\frac{dI}{dt} = \beta IS - vI$$
$$\frac{dR}{dt} = vI$$

A Networked Agent-Based Approach



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- In this case, vertices represent people, and edges represent frequencies of interaction.

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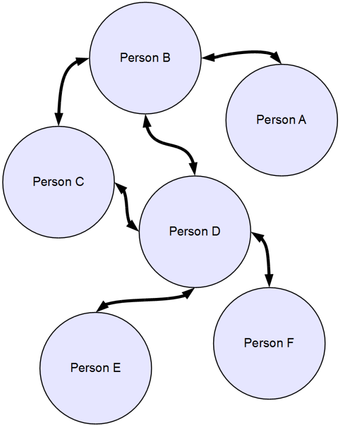

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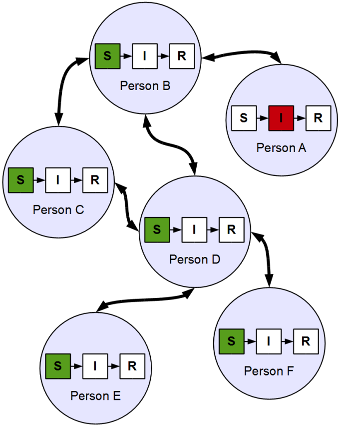

- Rather than lump the population into stocks, we let each agent track its own state.
- When an agent becomes infected, it infects its neighbors with a probability proportional to their interaction frequency.
- After a certain duration in the infected state, an agent transitions to the resistant state.

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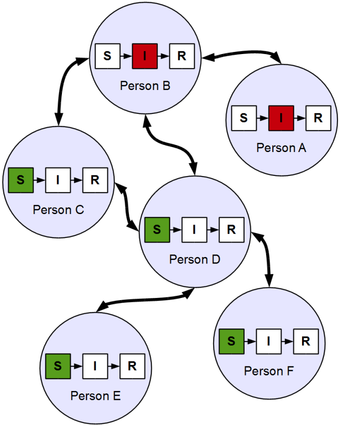

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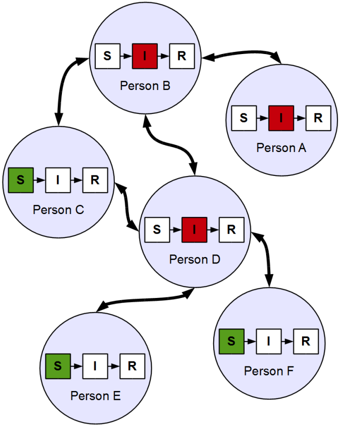

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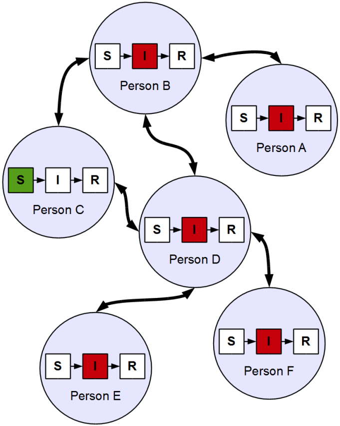

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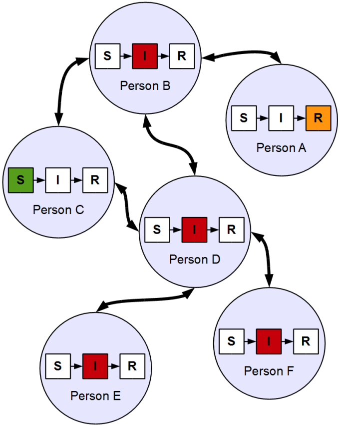

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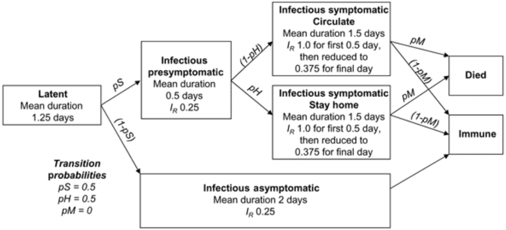
A More Realistic Disease Progression

- While the SIR state machine is simple, it unfortunately allows us too few parameters to adequately characterize a strain of influenza.
- In addition to adding more states, we also make the specific path of disease progression stochastic and couple an agent's infectivity with its state.



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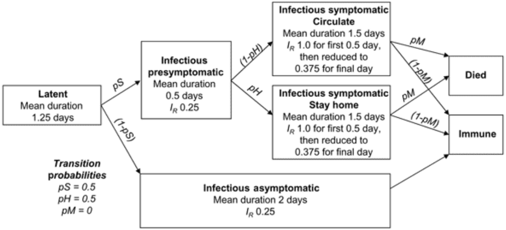

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Transmission Dynamics

- Whenever an agent advances to a new infectious state, it attempts transmission to each of its neighbors.
- First, its stay d in the state is randomly selected from an exponential distribution about the mean stay for the state.
- For each incident edge, the agent computes the transmission frequency f_I as

$$f_I = \overbrace{f_C}^{\text{frequency}} \cdot \underbrace{I_R \cdot I_A}_{\text{infectivity}} \overbrace{S_P \cdot S_A}^{\text{susceptibility}} . \qquad (1)$$

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Adaptation and intervention

- Some infected agents will stay at home and self-isolate, reducing their contact frequency with neighboring agents.
- Others will stay home from work to take care of a sick child.
- When an epidemic is detected (after a certain number of diagnoses occur in a given week), a number of interventions can be activated, such as
  - Antiviral treatment, which temporarily reduces infectivity and susceptibility.
  - School closures, in which contact frequency along all school edges is decreased by a compliance factor.
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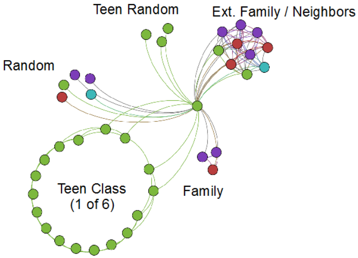
Generating Social Networks

- Rather than use an ideal generator, we instead use a layered approach to construct networks.
- As shown right, each node is the member of multiple subnetworks, such as a family or a classroom.



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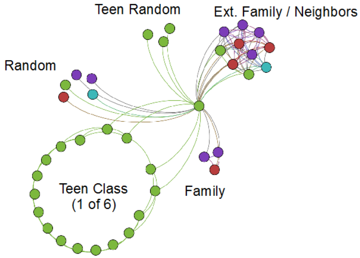

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Healthcare Environments

- Healthcare delivery is critical during an influenza outbreak.
- Healthcare sites are placed under tremendous strain during an influenza outbreak.
- Healthcare workers and susceptible patients are at a high risk of becoming infected in the healthcare environment.
- Goal: To understand the role of healthcare environments and minimize the impact of an influenza epidemic on healthcare availability.

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Healthcare Environments

- We introduced dynamic healthcare sites into our simulated community in which patients mix with each other and with healthcare workers by creating temporary "on-the-fly" networks.
- When an agent becomes symptomatic, it will, with a certain probability, go to a healthcare site and be accompanied by an adult escort from its family.
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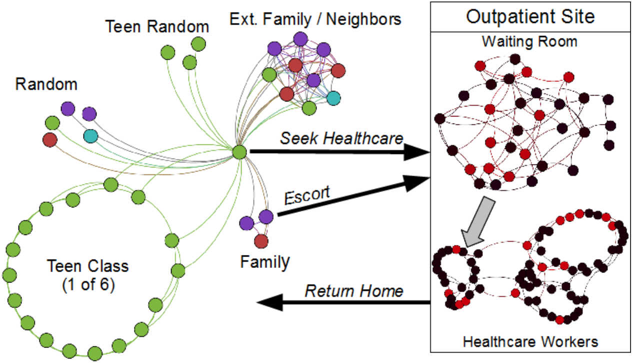

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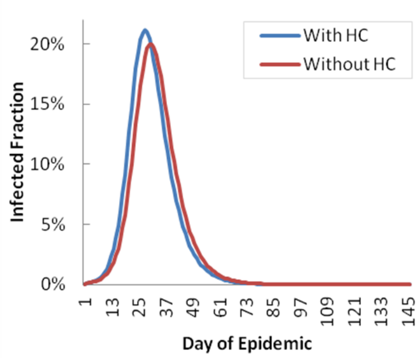
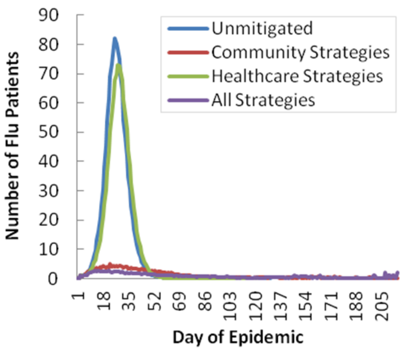
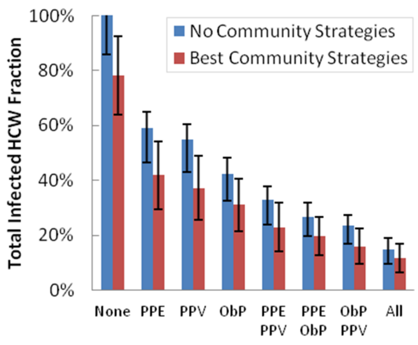
Effect of Healthcare Sites on Epidemic



Mitigating the Load on Healthcare Sites



Ranking of Healthcare Worker Interventions



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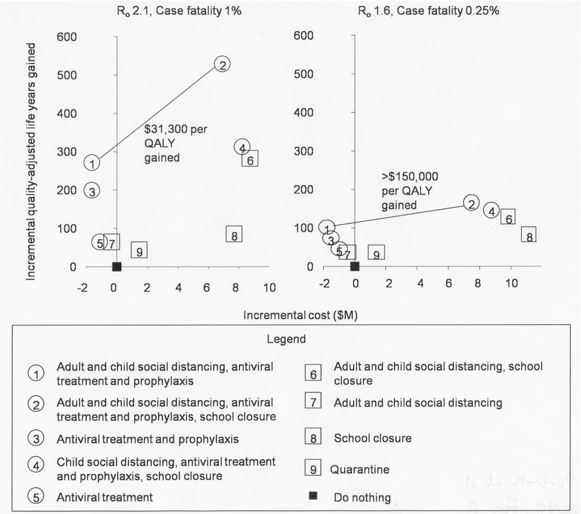

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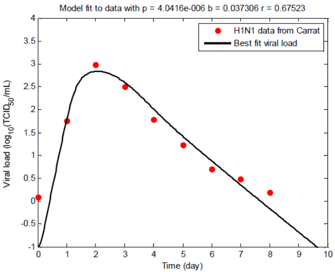
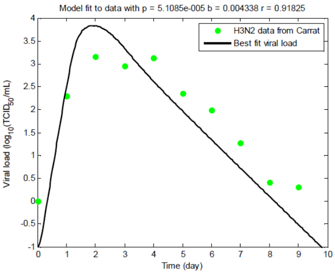
A Biophysical Model

- While on a DHS fellowship with us two summers ago, Danilo Šćepanović pioneered a new approach for modelling influenza transmission—by embedding a biophysical model of influenza inside each agent.
- The parameters governing a particular strain of influenza can be distilled down to p, the viral production rate, and b, the cellular infection rate.
- Additionally, each agent has an immune response rate r that we assign to members of the population from user-specified distributions.

A Biophysical Model





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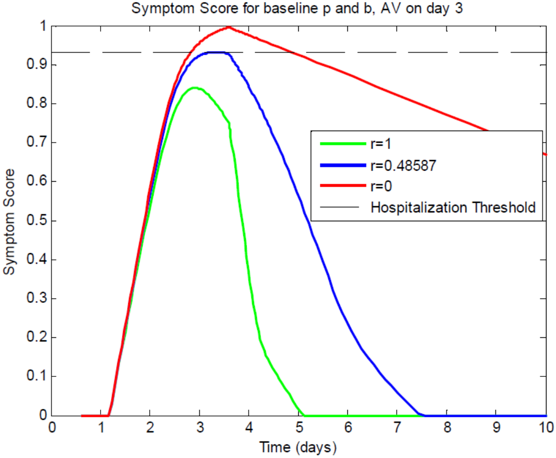

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